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Economic Impact Assessment Technique on Different Mitigation Methodologies of Electromagnetic Interference between special High Voltage Transmission Lines & Neighboring Gas Pipeline

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Abstract—**Electromagnetic fields produced by high voltage overhead transmission lines are still considered an important subject in several research areas due to their harmful effect on human health and environment. Environmental Impact Assessment studies(EIA)are very important to be carried out before establishing of power line projects to evaluate the electromagnetic effect on the project environment also its social and health impacts especially on nearby pipelines. This paper presents a comprehensive studyto the induced voltage levelsalonga Gas pipeline of 500 mm^{2}cross section area& 208 km length which lay in same right of way with an actual sophisticated overhead transmission line tower carrying four circuits (two 220 kV circuits & two 66 kV circuits) under different loading conditions. Three different mitigation methods were applied along the pipeline under normal and abnormal conditions (balanced, severe unbalanced loading and during different short circuit conditions). Mitigation techniques using cancellation wire, Gradient Control Wiresand using polarization cells were investigated. Results obtained showed that Gradient control wires & polarization cells give more efficient values for reduction of induced along the Gas pipeline. A model was developed using Alternative Transients Program (ATP)to simulate the whole system with the different mitigation methods. An Economical impact assessment technique was developed to determine the appropriate number & position of polarization cells to maximize its effect & minimize the cost with regard to the pipeline lifetime.**

Index Terms—**AC Induced voltage, Gas pipeline, Power lines,Mitigation Methods,ATP Program**

i. INTRODUCTION

Over the last decades, various utilities have been forced toshare the same distribution corridors for their networks. Themain reasons for that were the strict environmentalregulations that made it very difficult and time consuming tochoose another corridor and the higher financial costs a newcorridor would inflict. This resulted in situations where gas,water or oil supply utilities are sharing the same rights-ofwaywith overhead High Voltage Power Lines (HVPL) or ACrailway systems for several kilometers and in proximity toeach other.The electromagnetic fields generated by high voltagepower lines result in AC interference to nearby metallicstructures.(1)

There are three basic methods by which ac currents and voltages can be induced on metallic structures near ac power lines. The first one is electrostatic coupling where the structure acts as one side of a capacitor with respect to ground. This is only of concern when the structure is above grade. Second, EM induction may occur when the structure is either above or below ground. In this case, the structure acts as the single-turn secondary of an air-core transformer in which the overhead power line is the primary. Finally, resistive coupling is caused by fault currents from ac power towers that flow on and off the underground structure.

Stray currents due to these induced voltages can cause corrosion of metallic structures. The magnitudes of the induced voltages are often large-hundreds of voltages under EM induction and thousands of voltages during power-line faults. These high-current and voltage levels can produce a shock hazard for personnel and can damage the structure and related equipment, such as cathodic protection facilities. According to NACE International Recommended Practice RP0177, "Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems", potentials more than 15 V should be mitigated to reduce the hazardous potential level.(2)

Previous studies had showed that induced voltages in underground pipelines are influenced by specific parameters like HVPL current load, tower configuration, conductor length and angle, soil resistivity, etc. (4-6)

Most simulation softwares that provide capabilities for predicting and mitigating inductively coupled voltages on buried pipelines paralleling high voltage electric-power transmission lines have restrictions on the number of pipelines, transmission lines and direct bonds that can be modeled while ATPhasn't this limitations.
This method can deal with any number of transmission lines with different configuration and take into consideration groundings & soil resistivity. Also, there is no need to separate the problem in sections where the pipe is parallel or not to the transmission line(s). In addition, the effects of phase wire transposition are taken into account.
In this work a special tower configuration (carrying four circuits) & a typical Gas pipeline which in close proximity to the transmission line rote was simulated using ATP Program, induced voltages were calculated under normal & abnormal conditions. Three mitigation techniques were modeled and applied to the studied cases. Induced voltage levels were obtained using eachtechniqueindividually. An Economical impact assessment technique was developed and determined the appropriate number & position of polarization cells to maximize its effect & minimize the cost with regard to the pipeline lifetime.

ii. GENERAL SYSTEM LAYOUT

Consider the system in Fig. 1 showing the interactionbetween a power transmission line with specialtower configuration carrying four circuits (2 circuits 220 kv& 2 circuits 66kv) with a steel gas pipeline(Taba-Sharm Gas pipeline, API 5LX52, 20 inch Diameter , 0.5 inch thickness, 208 Km, 70 Bar) which runs in the same right of way for more than 57Km& designed to transmit 6 Million Cubic meter Gas per day.

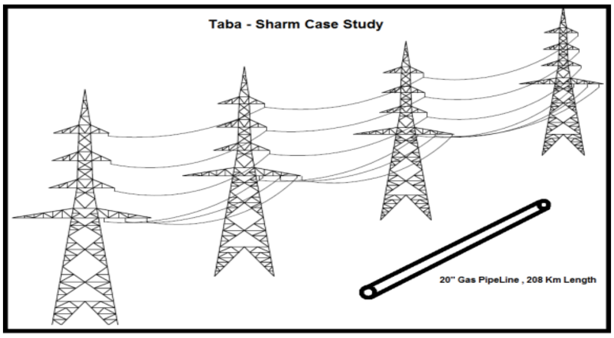


Fig.1

Fig.2

iii. DESCRIPTION OF METHOD

A. Theoretical Model

The proposed mathematical model is based on Maxwell's laws and nodal model of power transmission systems lines. The general model for power line transmission systems is based on the following:

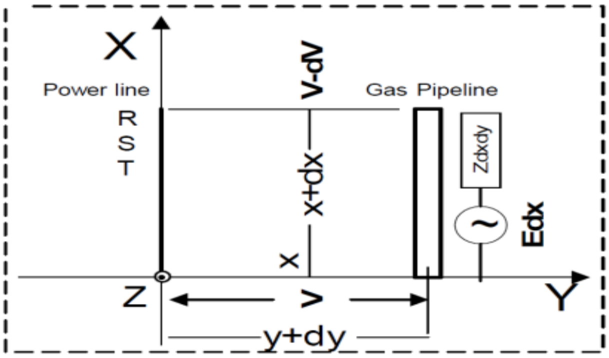


Fig.3

a segmented format consisting of discrete lengths depending on the gas pipeline position. The segmentation is considered in axis X and another in axis Y.
The dx shown in Fig. 3 represents the parameters' variation along the gas pipeline and power line, dy represents the parameters' variation with the distance between power line and pipeline.

$$-\left[\frac{dV}{dx}\right] = [Z'][V(x)]$$
$$-\left[\frac{I(x)}{dx}\right] + [Y'][V(x,y)] = 0 \qquad (1)$$

Where:
V: is the voltage in the power line
I :is the current flowing in the power line
Z': is the impedance distributed along the line
Y': is the admittance distributed along the cross sectionbetween power line, ground and gas pipeline.
For a longitudinal and cross-sectional variable system the equations above is expressed from the Fig. 3 as:

$$\frac{dV(x,y)}{dxdy} = Z`I(x,y) - E$$
$$\frac{dI(x,y)}{dxdy} = Y`V(x,y) \qquad (2)$$

Where:
E is the induced voltage on the pipeline per unit length, fora representation of the pipelinenetwork in a segmented formatconsisting of discrete lengths of pipeline.
The magnetically induced voltage over the gas pipelineconsidering three-phase system is calculated from:

$$-\frac{dE}{dxdy} = Z_{PA-reduce} I_A + Z_{PB-reduce} I_B$$

$$+ Z_{PC-reduce} I_C \quad (3)$$

The electrostatically induced voltage over thegas pipelineis calculated from:

$$0 = C_{PA-reduce} V_A + C_{PB-reduce} V_B$$

$$+ C_{PC-reduce} V_C + C_{PP-reduce} E$$

…..(6)

iv. LINE CIRCUIT REPRESENTATION FOR ATP-DRAW

The equivalent circuit for the 4 circuits (2circuits 220 Kv& 2 circuits 66 Kv) & the Gas pipeline is constructed as shown in Fig. and it considers mitigation wires& polarizationCells.

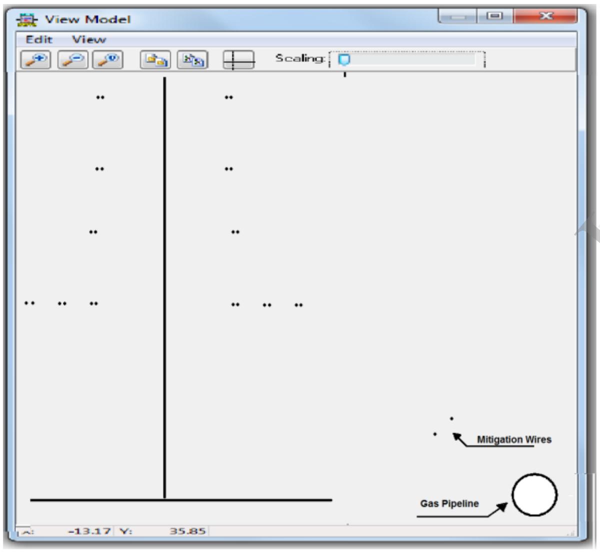
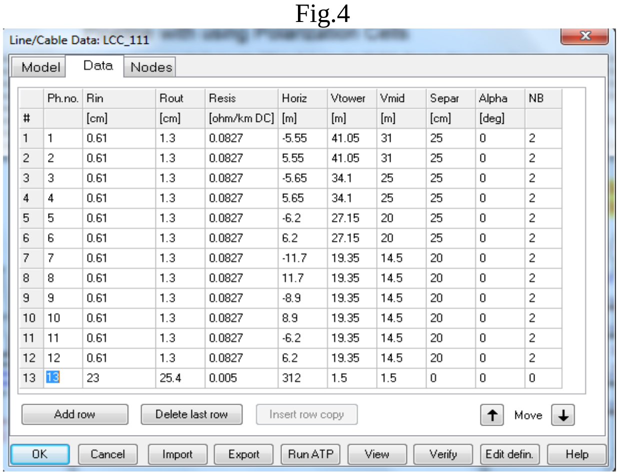


Fig.4



#	Ph.no.	Rin [cm]	Rout [cm]	Resis [ohm/km DC]	Horiz [m]	Vtower [m]	Vmid [m]	Separ [cm]	Alpha [deg]	NB
1	1	0.61	1.3	0.0827	-5.55	41.05	31	25	0	2
2	2	0.61	1.3	0.0827	5.55	41.05	31	25	0	2
3	3	0.61	1.3	0.0827	-5.65	34.1	25	25	0	2
4	4	0.61	1.3	0.0827	5.65	34.1	25	25	0	2
5	5	0.61	1.3	0.0827	-6.2	27.15	20	25	0	2
6	6	0.61	1.3	0.0827	6.2	27.15	20	25	0	2
7	7	0.61	1.3	0.0827	-11.7	19.35	14.5	20	0	2
8	8	0.61	1.3	0.0827	11.7	19.35	14.5	20	0	2
9	9	0.61	1.3	0.0827	-8.9	19.35	14.5	20	0	2
10	10	0.61	1.3	0.0827	8.9	19.35	14.5	20	0	2
11	11	0.61	1.3	0.0827	-6.2	19.35	14.5	20	0	2
12	12	0.61	1.3	0.0827	6.2	19.35	14.5	20	0	2
13	13	23	25.4	0.005	312	1.5	1.5	0	0	0

Fig.5

v. DIGITAL SIMULATIONCASES OF STUDY

Four typical configurations were considered:
1) Non-grounded gas pipeline.
2) Non-grounded gas pipeline with a parallel mitigation wire system placed at 0.8 m over the gas pipeline.
4) Non-grounded gas pipeline with a grounded parallel Gradient Control wire system placed at 0.8 m over the gas pipeline.
3) Grounded gas pipeline using Polarization cells.
The Electrostatically induced voltage and the magnetically induced voltage due to these power lines were determined at

Case 1:8% unbalance in loading during normal conditions.
Case 2: Heavy unbalance in loading during normal conditions.
Case 3: Single line to ground fault at circuit 1 (220 kv).
Case 4: Line to Line fault at circuit 1 (220 Kv).
Case 5:Single line to ground fault at circuit 3 (66 kv).
Case 6: Line to Line fault at circuit 3 (66Kv).

Table 1:show the maximum inducedvoltage peak for all cases

Circuit Topology / Circuit Condition	**Maximum Peak Voltage on Pipeline without Mitigation**	**Maximum Peak Voltage on Pipeline Using Gradient control wires**	**Percentages of Voltage Reduction using Gradient control wires**	**Maximum Peak Voltage on Pipeline Using Polarization cells**	**Percentages of Voltage Reduction using Polarization Cells**	**Maximum Peak Voltage on Pipeline Using Cancellation Wires**	**Percentages of Voltage Reduction using Cancellation Wires**
Steady State with Light Unbalance on Circuit 1(220 Kv)	71.2 v	7.6 v	89.4 %	13.3 v	82 %	62.29 v	12.7 %
Steady State with Heavy Unbalance on Circuit 1(220 Kv)	249.3 v	26.9 v	89.3 %	46.6 v	82 %	217.8 v	12.7 %
L-G Fault on Circuit1 (220 Kv)	30.3 Kv	4.7 Kv	84.5 %	12.37 Kv	60 %	28 Kv	7.6 %
L-L Fault on Circuit1 (220 Kv)	57.6 v	7.6 v	86.9 %	12.3 v	79 %	48 v	16.7 %
L-G Fault on Circuit3 (66 Kv)	6.49 Kv	0.92 Kv	85.9 %	2.5 Kv	61 %	5.8 Kv	11 %

Table 1

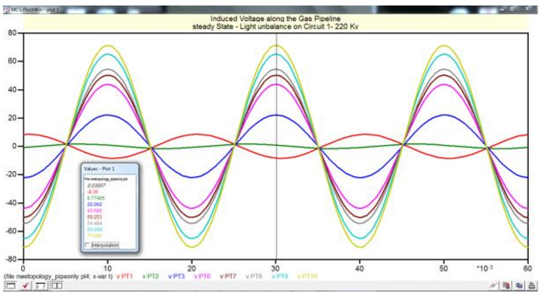


Fig.6Case1 Light unbalance on circuit 1 – Pipeline without mitigation.

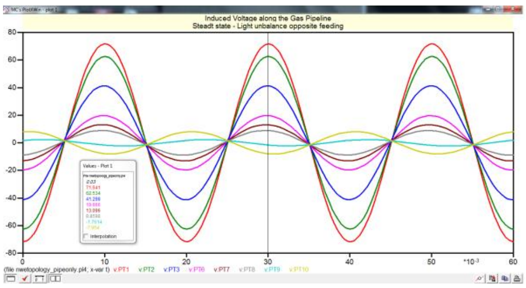


Fig.7Case1 Light unbalance on circuit 1 – Pipeline without mitigation.(opposite Feeding)

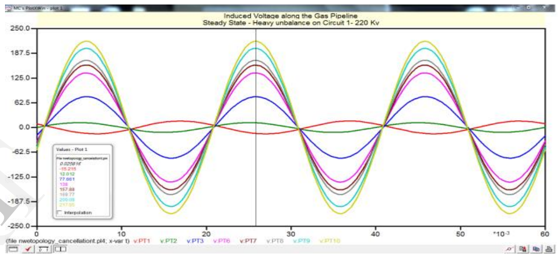


Fig.8Case2 Heavy unbalance on circuit 1 – using cancellation wires.

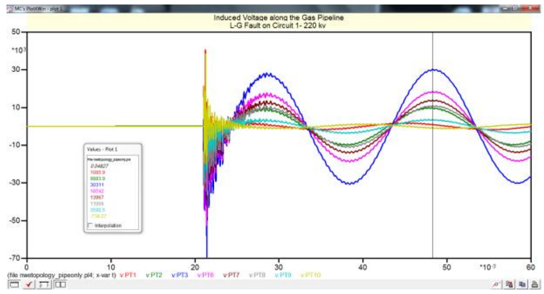


Fig.9Case3 Line to ground fault on circuit 1– Pipeline without Mitigation.

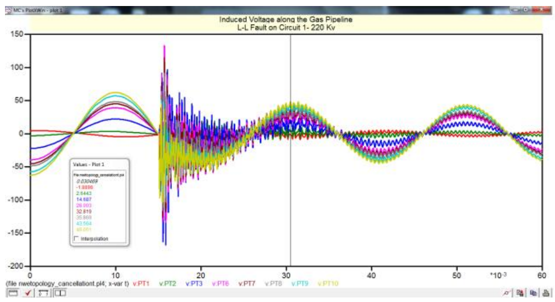


Fig.10 Case 4 Line to line fault on circuit 1 – using cancellation wires.

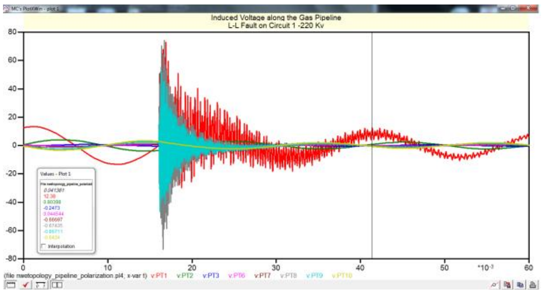


Fig.11Case 4 Line to line fault on circuit 1 – using polarization cells.

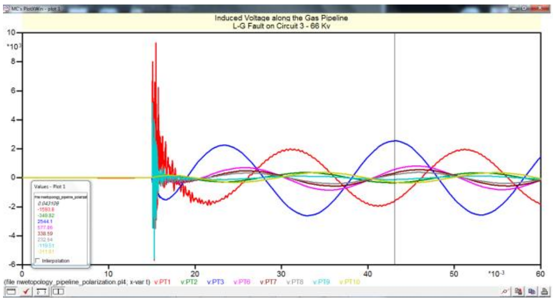


Fig.12Case 5 Line to ground fault on circuit 3 –using Polarization cells

vi.CONCLUSION

Induced voltage along the Pipeline was investigated at normal an up normal conditions, different types of mitigation methods were also investigated. Economical study was carried out for different solutions & Results showed that polarization cells is the most economical solution compared by cancellation wire & Gradient control wires even Gradient Control wires gives more efficient values. Polarization cells cost around 1% of pipeline capital cost compared to 5% to Gradient control wires & Cancellation wires.

Results showed also that the most severe cases that have line to ground fault and the least severe line to line fault which have an explanation that the fault current when return in the second phase cancel the electromagnetic field of the first one.Un balanced loading effect was investigated and results showed that it have a great effect on the induced voltages on the pipeline. It also observed that voltages collapse along the pipeline in the direction of circuit current & when current direction is reversed voltages collapse at the other end of the pipeline, which may lead to unexpected sever corrosion at the other end of the pipeline unless be considered & mitigated .

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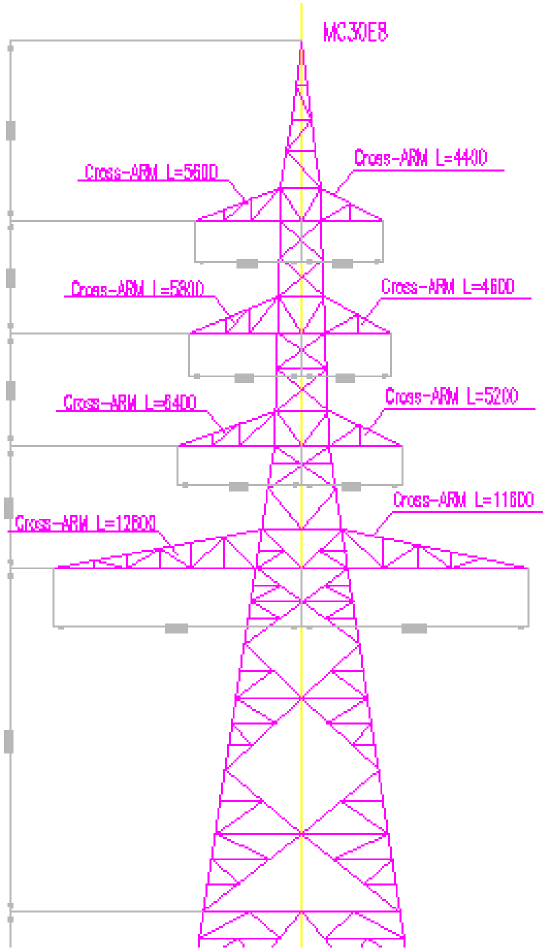
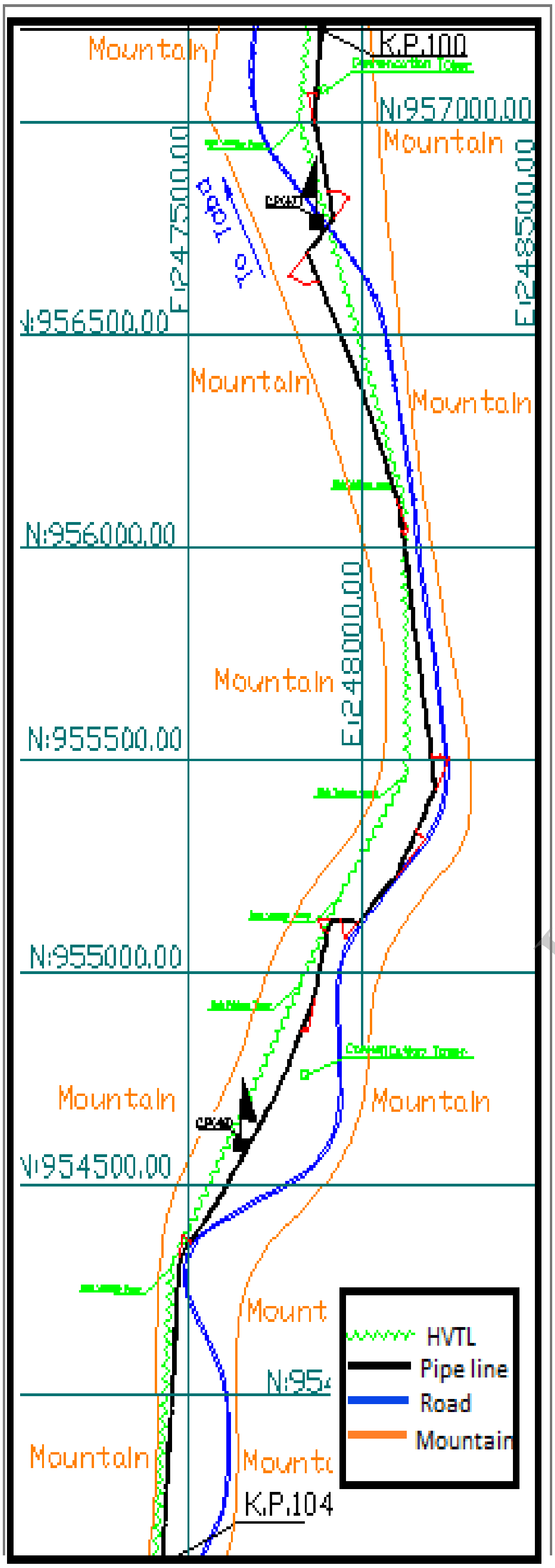


Fig.13

Fig.14

Fig.15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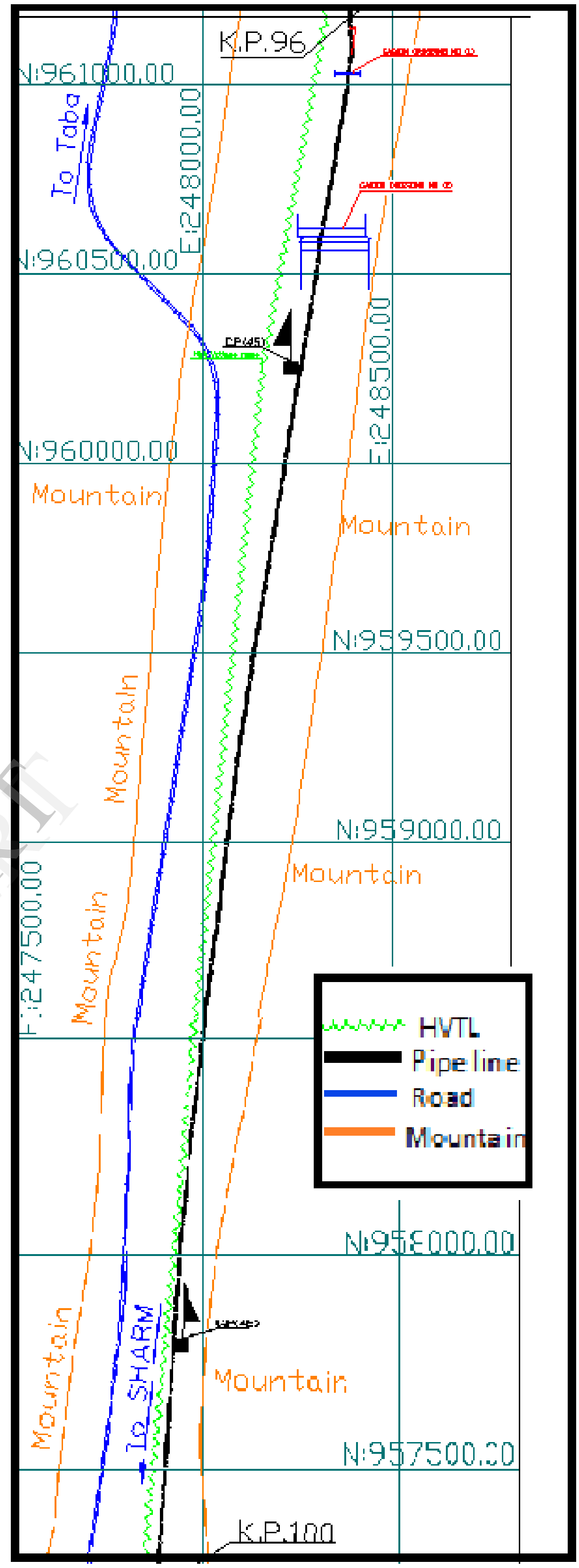
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Fig.16

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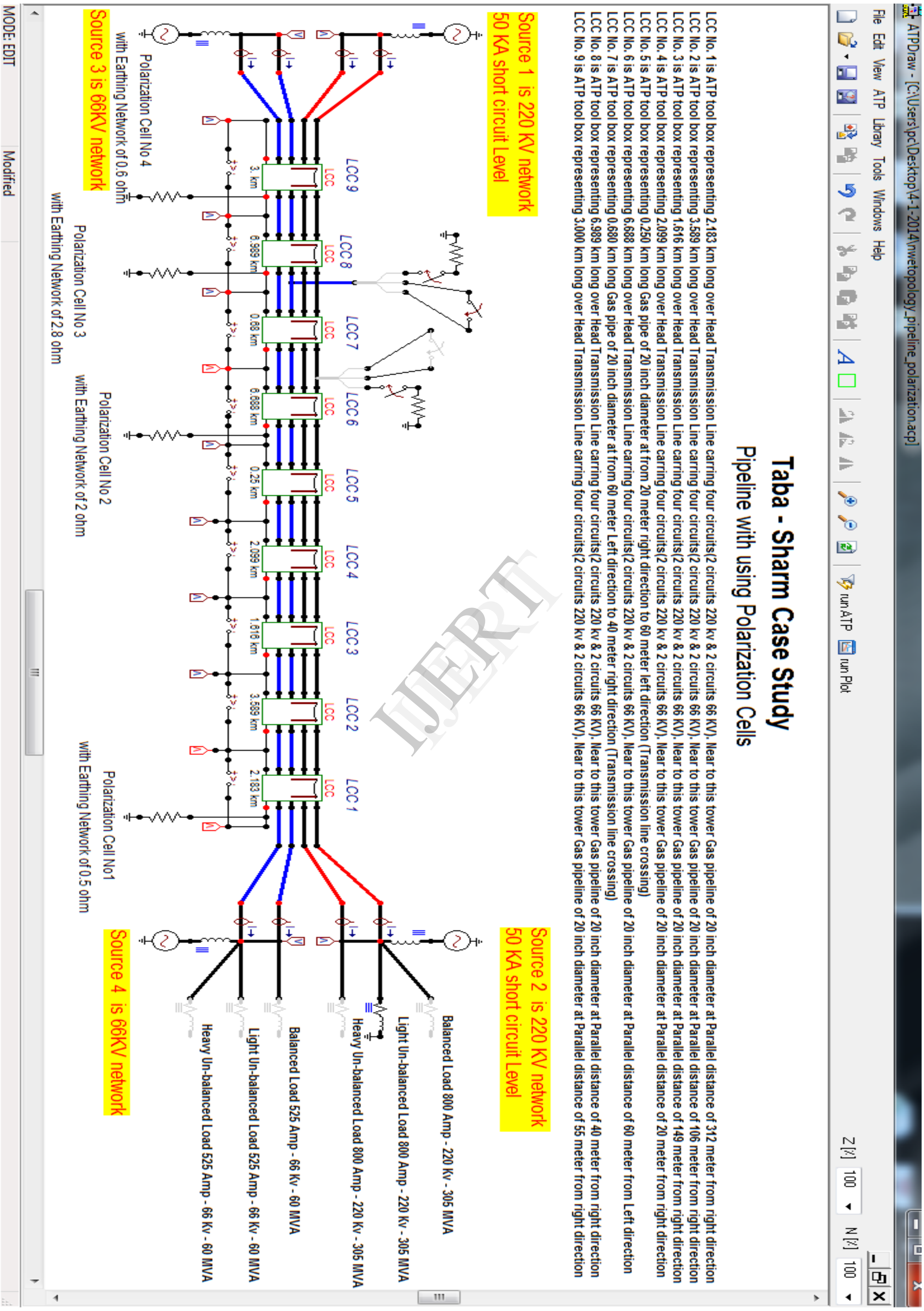
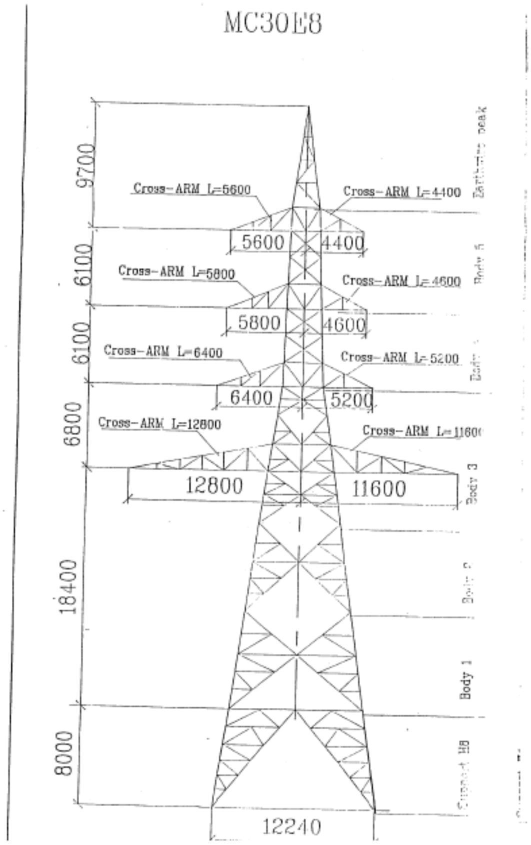


Fig.17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5200
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12800
11600
Body 3
Body 1
12240

Fig.18